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FISHERY INVESTIGATIONS

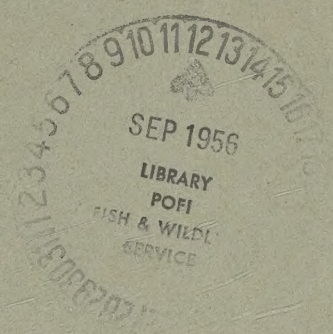
Series II *Volume* XX *Number* 4

Phytoplankton and the Herring

Part V

D. H. CUSHING

Fisheries Laboratory
Lowestoft



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Phytoplankton and the Herring. V*

I. INTRODUCTION

x papers have been published showing that certain distributions of phytoplankton have ected catches of herring during the East Anglian season. (Hardy, 1926; Savage, 1930; vage and Hardy, 1935; Savage and Wimpenny, 1936; Henderson, Lucas and Fraser, 1936; aham, 1938.) There were two factors reported in this series: (a) the apparent exclusion herring by phytoplankton as shown by a comparison of diatom catches with con- mporaneous drift net catches of herring, i.e. when diatom catches were high, drift net ches from the same positions were low; hence, exclusion could account for fluctuations m week to week during the fishery: (b) the deflection or delay in the migration of the ring, traceable to this exclusion.

The thesis of exclusion derives from the work of Pearcey (1885) and Bullen (1908); or catches of herring off Shetland in the summer, and of mackerel off Plymouth in the ing, were found in 'weedy water'. In 1926, Hardy published the results of a comparison he East Anglian fishery between drift net catches of herring and phytoplankton catches h a plankton indicator towed at a depth of 5 m.; six records of green discs coincided h herring catches ranging from $\frac{1}{2}$ to 6 crans (average 2·17), and six records of blank cs with catches ranging from 15 to 45 crans (average 25·33). Hardy's observations ended the hypothesis of exclusion from the feeding fishery observed by Pearcey in the nmer to the East Anglian autumn fishery, in which the fish do not feed. Further servations of this type were made by Henderson *et al.* (1936).

The first evidence of a deflection of migration was given by Savage (1930). Poor catches the first week in November, 1927, were associated with a patch of *Phaeocystis* across assumed path of the herring migration to Smith's Knoll; the area of high catches s subsequently found to be 40 miles north-east of Smith's Knoll – an apparent deflection migration. Savage and Hardy (1935) published evidence that poor fisheries occurred in se years when the phytoplankton was dense; Savage and Wimpenny (1936) showed that East Anglian fishery was delayed for three weeks when a very dense patch of phyto- nkton was found across the assumed approach path of the herring. Another feature nted out by Savage and Wimpenny was that areas of drifter catches were sometimes served to lie close to phytoplankton patches. The phytoplankton species described were rly always *Rhizosolenia styliformis*, Brightw. and *Biddulphia sinensis*, Grèv.

The consequence of this work was that phytoplankton surveys were carried out before d during each herring season, in order to give warning to the fishermen of a possible lay to, or 'interference' with the fishery. Hence, it would be useful to know the threshold nsity, in numbers per unit volume, at which phytoplankton excludes the herring, or at ich the migration of the herring is diverted or delayed. Cruises with three ships in mpany were planned in order to find two facts: (a) the density at which exclusion appears, estimated by the comparison between drift net catches and plankton catches, i.e. the nsity in numbers per unit volume at which catches of herring start to fall: (b) the density numbers per unit volume at which migration was deflected.

rts I-IV in this series are listed in the bibliography.

II. METHOD

1. October 1948

A preliminary survey was carried out by R.V. SIR LANCELOT in the area: –South-West Patch the Dogger Bank, Outer Dowsing L. V., Cromer Knoll and the Silver Pits. The survey to the form of Hensen net stations (for phytoplankton), on a grid, of which the latitudi lines were 15 miles apart; this distance was so chosen that any line of stations was out of range of fetch of the tidal streams from either of the adjacent lines. The stations are mark on Fig. 1. A patch of *R. styliformis* was revealed in the western part of this area. At same time, a patch of pelagic fish was found by echo survey (Cushing, 1952); the ec sounder used was a Kelvin and Hughes MS XII. Fig. 3 in Cushing (1952) shows a co parison between this particular echo survey and the distribution of drifter landings Lowestoft and Great Yarmouth during the cruise period. There is quite good agreeme which identifies generally the fish recorded as herring; this does not mean that all reco are necessarily due to herring, but that the majority must be.

Although diatoms are nowadays usually sampled with a water bottle, they were ta on this cruise with a Hensen egg-net for two reasons: (a) *Rhizosolenia styliformis* *Biddulphia sinensis* are large diatoms and only a small proportion escape through the used (60 meshes to the linear inch): (b) all previous work from Lowestoft and Hull carried out using a Hensen egg-net and a plankton indicator respectively, both of wh filter water through 60 mesh silk.

When the main distribution of the diatom patch was known from the results of preliminary survey, R.V. SIR LANCELOT and R.V. CLUPEA made a rendezvous at sea midday on the 6th October). It was then arranged that each ship should carry out a se of traverses across the western and eastern edges of the plant patch respectively. Hen egg-net stations were made at both ends of each traverse and intermediately; the ec sounders of both ships were run continuously between plankton stations. This part of cruises is illustrated in Fig. 2(a), showing the positions of stations occupied by each sh Detailed navigation was carried out by SIR LANCELOT with the aid of the Decca navigato

On the morning of 7th October, three horizontal hauls were taken from the R.V. LANCELOT in the western part of the plant patch at surface, midwater and bottom, usin Clarke-Bumpus sampler (silk used was 60 meshes to the linear inch). This set of hauls repeated in the eastern part of the patch. The result of both sets of hauls was that the den of plants in the midwater was about four-thirds of that in the surface and bottom lay this was taken to mean that no significant vertical stratification in plant numbers had ta place. Associated with this observation is the fact that the first part of the cruise, the p liminary survey, was carried out in heavy weather, which must have caused deep mix

During the afternoon of 7th October, the drifter fleet was seen to assemble on southern edge of the dense phytoplankton patch, in the region of the Sole Pit. SIR LANCE and CLUPEA made rendezvous here and Hensen net observations were made along drifters; the names and numbers of each were recorded in order to obtain records of catches in crans afterwards. During the early morning of 8th October, R.V. PLATESSA t similar observations. In all, 59 observations were taken in 18 hours.

2. September 1950, and October 1951

During these years, the intention was to repeat the 1948 series of observations an possible to trace the movement of the herring patches by means of echo survey. In 19 two cruises were made in September, covering the probable area of the approach of herring to Smith's Knoll. A patch of *Rhizosolenia styliformis* was found in the regio the Dogger Bank at a density of about 300,000/m.^{3}. The drifter fleet was not in contact v the diatom patch, although the German herring trawlers were fishing right in the mi of it. In 1951, the drifters were not in contact with the plant patch in October, so ag no attempt was made to repeat the 1948 observations.

III. RESULTS

1. Echo Unit and Plant Distributions on the Preliminary Survey

he preliminary survey is illustrated in Fig. 1. This figure shows the results of the diatom ounts at each station on the echo survey chart. It is clear that pelagic fish have not been cluded in the horizontal dimension by the patch of *Rhizosolenia styliformis*, because ur out of six phytoplankton stations of 10,000/m.^{3} + lie within the pelagic fish patch.

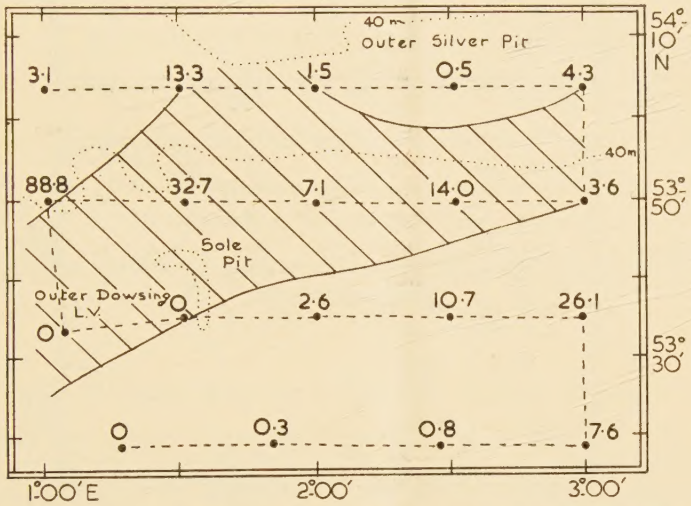

Fig. 1. *Echo survey and plant distributions between the Silver Pit and the Outer Dowsing.*
Results of echo survey as echo units per unit time steamed shown in the shaded area. Numbers of *Rhizosolenia styliformis* as thousands per m.^{3} are marked on the chart at each station. Depth contours at 40 m. are shown.

2. Echo Survey and Plant Distributions from the Detailed Traverses

he results for all stations in plant and echo unit distributions, are shown in Figs. 2(a) and) respectively. Results from the traverses made by SIR LANCELOT and CLUPEA are included ith some of those from the preliminary survey. Comparison of Figs. 2(a) and 2(b) shows at there has been no exclusion of pelagic fish by the plants in the horizontal dimension.

It might, however, be quite possible that the plants were all distributed at the surface nd that the fish were all underneath. Then, with no horizontal exclusion there might erhaps however be a vertical exclusion. We have already shown that there was little if ny stratification of the plants. As has been noted already, the first part of the cruise in October, 1948, was carried out in quite heavy weather, following a gale, so the water was resumably quite turbulent; hence, a pronounced vertical stratification of the diatoms ould not be expected. During this period, the shoals of fish recorded by the echo sounder ere found at all depths and were not confined to the bottom levels. As the pelagic fish atch coincided reasonably well with the distribution of herring catches, it is clear that sh were able to rise into the drift nets within the plant patch. Thus, we may conclude that ertical exclusion did not take place.

It will be noticed that the pelagic fish, as recorded by the echo sounder, were not istributed with any relation at all to the boundary of the diatom patch as marked by the raverses across its edge, as one might expect if an exclusion had taken place. On the ontrary, there tends to be a very rough coincidence between the plant and fish distribu- ons; no significance is attached to this, as it is possible that the diatom patch is drifting cross the path of the herring migrations.

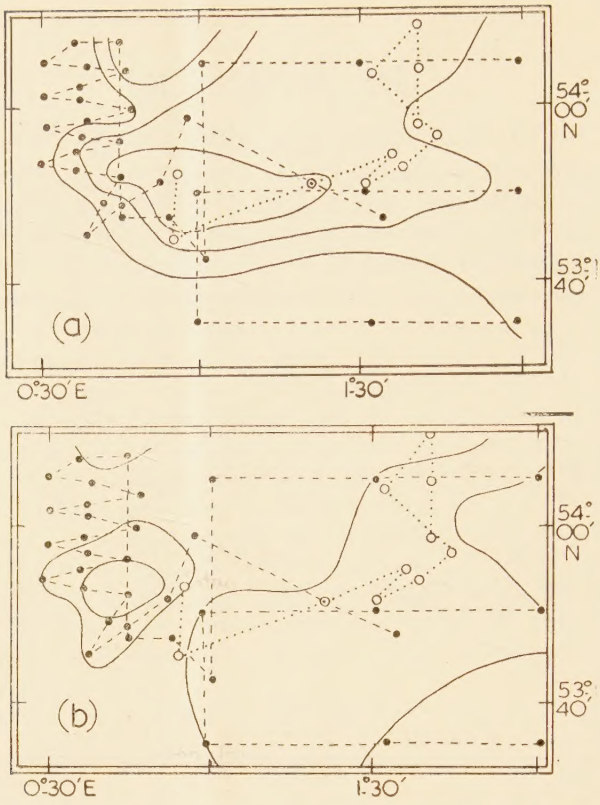

Fig. 2. *Diatom and echo unit distributions from the traverses over the edge of the diatom pat*

(a) Numbers of *Rhizosolenia styliformis* per cubic metre, contoured at 0–100, 100–10,0 10,000–40,000, 40,000 +

(b) Echo unit distribution at two levels of contour: 0–1 and 1 + units per unit time of steaming betw stations.

Cruise track of *Sir Lancelot* ●------●
Cruise track of *Clupea* ○.....○

3. Plant Densities and the Density of Echo Units Along the Traverses

In order to compare plant and echo distributions, an average diatom density betwe successive plankton stations was calculated. In order to use echo distributions of two sh moving at different speeds, the number of soundings on fish divided by the time steam between stations was used. This is equivalent to soundings on fish per unit distance.

Using the stations placed in the middle of and at each end of each traverse, plant a echo densities can be compared inside the patch and outside it. Taking the means of obser tions on the western edge alone, there were 0·31 soundings on fish per unit distance outsi the patch and 1·19 soundings on fish per unit distance inside the patch; the mean dens of *Rhizosolenia styliformis* outside the patch was 1,873/m.^{3} and inside it, it was 21,911/m Combining the mean results for the western edge and the eastern edge, there were 0·2 soundings on fish per unit distance outside the patch and 0·281 soundings on fish per u distance inside it; the mean density of *Rhizosolenia styliformis* outside the patch w 2,731/m.^{3} and that inside it was 25,155/m.^{3}. This is another way of stating that there was exclusion in the horizontal dimension. Again, no significance is attached to the fact th the fish shoals appear to be concentrated in the plant patch at the western edge of the ar

These results are expressed in another way in Fig. 3. The number of soundings on f per unit distance are plotted on the abscissa and the ordinate is marked in increasi densities of *Rhizosolenia styliformis*. The graph shows the lack of any boundary to t distribution of pelagic fish, up to a density of 40,000 diatoms per m.^{3}.

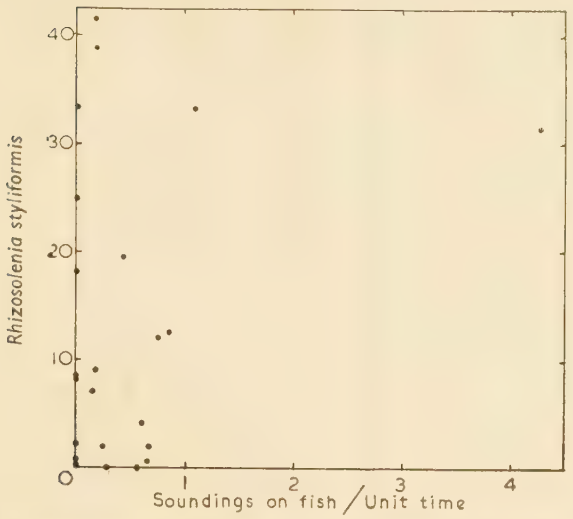

Fig.3. *Relation between numbers of diatoms and echo units along the traverses over the edge of the diatom patch.*

4. Hensen Egg-net/Drifter Comparison

As the drifter fleet was spread across the edge of the plant patch, a wide range of plant densities was available for a diatom/drifter catch comparison; the correlation coefficient between the two variables in Fig. 4 is 0·04 ($n = 62$) which means that they are independent.

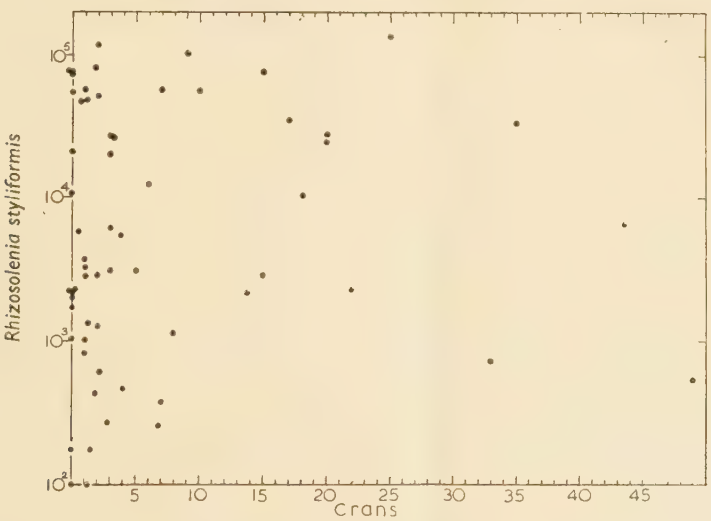

Fig.4.

Correlation between numbers/m.^{3} *of* Rhizosolenia styliformis *and catches of herring in crans.*

The results may be split in a number of ways and χ^2 tests of independence carried out. Table I shows these results.

Table 1*: Tests on the independence of densities of herring and* R. styliformis

Part 1*:* 2×2 *table between densities of* R. styliformis *and crans of herring*

Crans	*R. styliformis* $< 23{,}193/\text{m.}^3$	*R. styliformis* $> 23{,}193/\text{m.}^3$	
High	(a) 8	(b) 8	$\frac{(a+b)}{16}$
Low	(c) 33	(d) 13	$\frac{(c+d)}{46}$
	$\frac{41}{(a+c)}$	$\frac{21}{(b+d)}$	62

$$\chi^2 = \frac{\left[(ad-bc)-\frac{n}{2}\right]^2 n}{(a+b)\,(c+d)\,(a+c)\,(b+d)} = 1{\cdot}628;\ DF = 1;\ p = 0{\cdot}2$$

i.e. each variable is independently distributed about the mean.

Part 2*: Table between various densities of* R. styliformis *and high and low crans*

Crans	*R. styliformis* cells/m.^{3}			
	0 – 1,000	1,000 – 10,000	10,000 – 100,000	100,000+
5+	4	6	9	2
5–	9	17	14	1

$$\chi^2 = 0{\cdot}213;\ DF = 3;\ p = 0{\cdot}98$$

which means that each variable is independently distributed.

Part 3*: Table between densities of* R. styliformis *and soundings on fish per unit time alo traverses*

Soundings on fish/unit time	*R. styliformis* cells/m.^{3}		
	0 – 1,000	1,000 – 10,000	10,000 – 100,000
$>$ 0·25	10	13	4
$<$ 0·25	1	4	8

(*Sir Lancelot* only)

$$\chi^2 = 0{\cdot}79,\ DF = 2,\ p = 0.7,$$

which means that each variable is independently distributed.

The results of the tests given in Table I show that catches of herring and densities of *Rhizosolenia styliformis* are independent up to 100,000 diatoms per m.^{3}. This is so, whether abundance of herring is estimated with the echo sounder or with the drift net and comparisons are made at three or four levels of plant density in numbers.

Since 1921, densities greater than 100,000/m.^{3} have been observed. Using the charts, given in Savage and Hardy (1935) and Savage and Wimpenny (1936), the following table of peak densities has been compiled.

Table II*: Stations of highest density of* Rhizosolenia styliformis 1921-34

1921	1 station of	100,000/m.^{3}
1922	4 stations of	100,000/m.^{3}
1923	2 stations of	20,000/m.^{3}
1924	2 stations of	4,000/m.^{3}
1925	7 stations of	100,000/m.^{3}
1926	2 stations of	100,000/m.^{3}
1927	1 station of	4,000/m.^{3}
1930	1 station of	20,000/m.^{3}
1931	1 station of	200,000/m.^{3} (and 1 station off Texel Island of 700,000/m.^{3})
1932	3 stations of	500,000/m.^{3}
1933	1 station of	1,000,000/m.^{3} + 6 of 100,000/m.^{3}
1934	3 stations of	100,000/m.^{3}

Note: In 1924, a year in which phytoplankton was said to have no effect on the fishery, there were two stations of 600,000/m.^{3} of *Biddulphia sinensis*.

Thus the results presented in Fig. 4 appear to be applicable to all the series of years except 1931, 1932 and 1933. The conditions that produced very high densities (i.e. more than one station greater than 200,000/m.^{3}) occurred thrice in twelve years. (No samples were taken in 1928 and 1929.) Again, the peak density often occurs too late to delay the fishery, at the end of October or at the beginning of November on the S.W. patch of the Dogger, off Texel Island or off the Dutch coast. To delay the fishery, the significant time for high densities is the end of September on the Dogger Bank and the first half of October between the Dogger and the Norfolk Banks. At this period, in this limited region densities of diatoms of 100,000/m.^{3}+ were only recorded in 1933 and 1934. (There was one dense station in 1932 near the S.W. patch on 14th October, but it was isolate.) 'Interference' with the fishery may take place anywhere; Table II covers all years up to 1934, except 1928 and 1929, when no plankton observations were available.

It would be useful now to compare the catching power of the Hensen egg-net with that of the miniature plankton indicator used by Henderson, Lucas and Fraser in 1934 (1936). From a comparison of the region sampled by Savage and Wimpenny with the Hensen egg-net in 1934, and that sampled by Henderson *et al.* with the miniature indicator, it appears that the maximum density found by the Hensen net between 6th-13th October was 20,000 diatoms/m.^{3}; from 19th-22nd October it was 30,000 diatoms/m.^{3}. Nothing has been published about the sampling efficiency of a miniature indicator, but it is presumably comparable to that of the ordinary plankton indicator (see Barnes, 1951, for an estimate of the coefficient of variation of a single haul with an ordinary indicator: – 75 – 100%). The mouth opening of the miniature instrument is $\frac{1}{4}''$ in diameter, so its area is $\pi/64$ square inches. In use, it was towed along the fleet of nets, from the port quarter, whilst they were being shot, which is about 2–2½ miles, or 3,520–4,400 yards. Assuming perfect filtration (Barnes, 1951, writes that the ordinary indicator probably filters the theoretical quantity of water) the catch may be expressed as

$$\text{the number of cells per } \frac{\pi}{64} \times \frac{3{,}520 \times 36}{12 \times 12 \times 12} \text{ cu. ft.} = 3{\cdot}6 \text{ cu. ft.}$$

We may assume that the catch was from about 0·1m.^{3}. The highest catch recorded by Henderson *et al.* is 2,280 cells of *Rhizosolenia*, which would be about 25,000 cells/m.^{3}. Evidently, the range of densities used in Fig. 4 adequately covers the range used by Henderson *et al.* (1936).

5. The Migrations of the Herring

The direction of approach of herring to the East Anglian fishery may be shown in two ways by the distribution of landings and by the use of echo-survey. The distribution of landings depends on the fleet behaviour, which, in turn, depends upon the position of the port. English driftermen come to East Anglia from Shields, so their base is transferred a considerable distance. As they return to port every night, their searching is influenced by their distance from port; thus, the English fleet tends to aggregate in late August and early September from Shields on the north-western slopes of the Dogger. After its transfer to Lowestoft and Yarmouth in late September or early October, the fleet tends to aggregate in the fairly deep water between the Dogger and the Norfolk Banks. By this time, the region over the Dogger Bank itself is covered by Dutch and German luggers and, since 1935, German trawlers in numbers. These fleets aggregate near the South-West patch of the Dogger, due north of the Norfolk Banks. If the fleets are aggregating efficiently, the route of the herring migration can be marked by the distribution of landings, from the deep water off Shields, to the Dogger in the region of the South-West patch, across the Pits to the Swatchways between the Norfolk Banks and Smith's Knoll.

This method, however, might well be misleading, because, although the Dutch and German fleets in late September have been in contact with fish shoals for a long time, the English fleet has to make a new contact. One might then suggest that there were Dogger fish that remained on the Bank and that there were East Anglian fish that slipped in through the Flamborough deep water, or over the eastern Dogger from the Heligoland Bight. This question is partly answered with the use of echo survey.

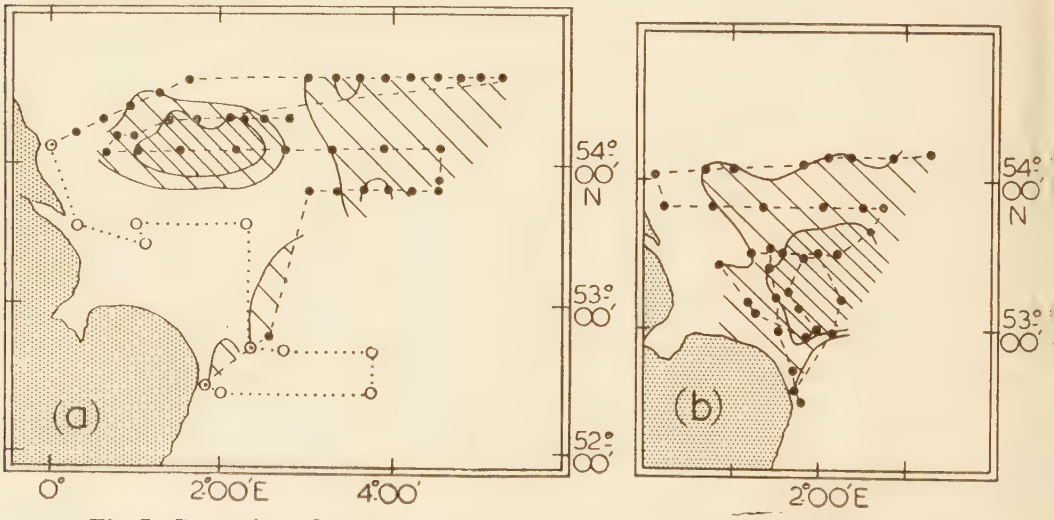

Fig. 5. *Successive echo surveys south of the Dogger Bank in September*, 1950

(a) The first half of Cruise XV, *Sir Lancelot*, 1950
Cruise track of *Sir Lancelot* ●------●
Cruise track of *Clupea* ○.....○
Echo units are contoured at two levels of density, 0–100 and 100 +

(b) The second half of Cruise XV, *Sir Lancelot*, 1950
Cruise track ●------●
Echo units are contoured at two levels of density, 0–100 and 100 +

Note: Echo units are not expressed as per unit time steamed, because *Sir Lancelot* made constant speed.

In September, 1950, the whole region was covered with a grid of stations (Fig. 5) from Whitby to 5°E and southward to the Norfolk Banks. A patch of pelagic fish was found in

uite dense concentration (Cruise XVa SIR LANCELOT, shown as a pecked line on the chart, d a cruise of CLUPEA, as a dotted line on the chart) on the South-West Patch of the ogger. This patch is described quite adequately by the cruise tracks of the CLUPEA and ruise XVa SIR LANCELOT; the only other comparable patch in the region is a small one tween 3° and 4°E. German trawlers were working in the region of the larger patch, tching herring in very large quantities. The next cruise (XVb SIR LANCELOT) was carried t in the same region, immediately afterwards ; the main patch of pelagic fish had apparently oved south to the Haddock Bank region. This patch was not observed anywhere on the uise track of R.V. CLUPEA which was carried out at the same time as Cruise XVa SIR NCELOT. There was, thus, a sharp southward movement towards the Norfolk Banks, own in Fig. 5, confirming the suggestion made in the sequence of Dutch and German ndings (see Fig. 9).

An interesting point about Fig. 5 is that Hensen net samples were taken in the centre the patch of pelagic fish during the first cruise (XVa, SIR LANCELOT). The densities of *hizosolenia styliformis* at the two peak stations were 250,000 and 300,000 cells/m.^{3}. ankton recorder results (for which I am grateful to Mr. K. M. Rae) for July-October ow a developing patch in the same region which reached peak densities of between 70,000 d 700,000 cells/m.^{3} in September. Thus the fish have moved straight through a dense tch of diatoms. One might argue that there was a marked vertical stratification, but this is ry unlikely as the wind was blowing strong to gale across these shallow waters during the st cruise (XVa, SIR LANCELOT). In their migration, from the S.W. Patch of the Dogger the Norfolk Banks, the herring were neither deflected nor delayed by a density of *hizosolenia styliformis* only exceeded in 1933 and 1934.

6. Summary of Results

the work described, no exclusion of herring by diatoms in the horizontal sense has been served. This has been tested by comparing the distribution of plants with that of echo-cords of pelagic fish. It has also been tested by comparing catches of herring at different nsities of *Rhizosolenia styliformis*. It is unlikely that exclusion in the vertical sense took ace at any time, because of rough weather conditions.

No deflection of fish migration by diatom patches was observed. If no deflection takes ace, delay of the fishery becomes unlikely.

These results are quite opposed to the conclusions summarized in the introduction, nich led to much effort in preparing warnings of 'weedy water' to the fishermen. These rlier conclusions which appeared so convincing, must be examined in some detail.

IV. DISCUSSION

1. Exclusion

nder this heading will be discussed Hardy's first results on *Phaeocystis* (1926) and those Henderson *et al.* (1936), continuing this work on the diatom patches. I think that these sults include two forms of error, a serial error and an error of location. The first may be ustrated in the first series of observations. They lasted from 13th October to 24th ovember, 1922 (see Fig. 6). Incidentally, very heavy catches (including one of 220 crans) ere landed from the region of the GALLOPER LIGHTVESSEL on 24th November, where one the low catches was observed. It can be shown that the mean catch in crans per week r the period 13th October-7th November was 76,000, whereas for the period 8th-24th ovember, this figure declined to 41,000 crans per week. The mean catch of the six drifters served in the first period was 22 crans and that of the six drifters in the second period as 5·3 crans. Thus there is a trend of catches, independent of the presence of *Phaeocystis*, nich has not been eliminated; this is a serial error. It is not suggested that this particular

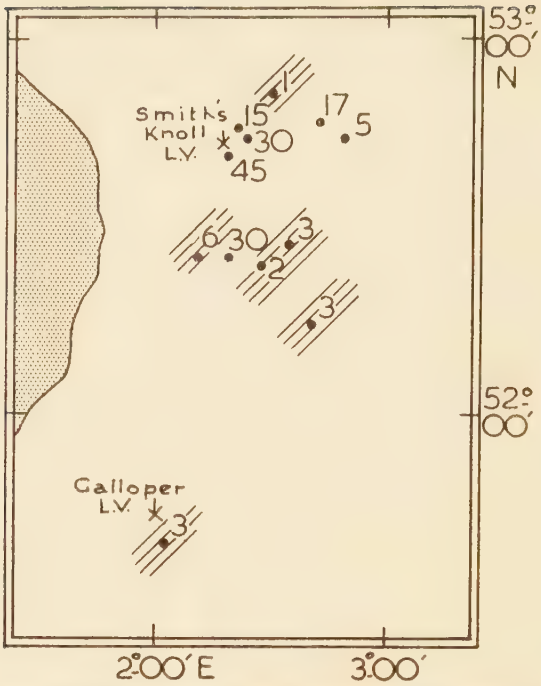

Fig.6. *The distribution of drifter catches contributing to Professor Hardy's table* (1926).

serial error (eliminated in the later work of Henderson *et al.*, 1936) causes the reduction i catch from 22 to 5·3 crans, but it is suggested that other serial errors might have come in e.g. the relation of the observed drifter to the rest of the fleet. By this is meant that th observed drifter for the first half of the period might be right in the centre of the flee profiting by the searching of the whole fleet, whereas in the second half of the series, th observed drifter might have been on the edge of the fleet. This is a very real possibilit for in November in the East Anglian fishery it has been shown (Cushing 1953) that th mean catch per statistical rectangle increases with the number of boats fishing in tha rectangle. This is taken to mean that in November (1951) highest catches were taken in th centre of the fleet, because the fleet as a unit, was searching efficiently. This effect was n apparent in October (1951), so between the two months there was a marked change in th habit of the fishery that is not likely to be obvious from the catches of a single drifter.

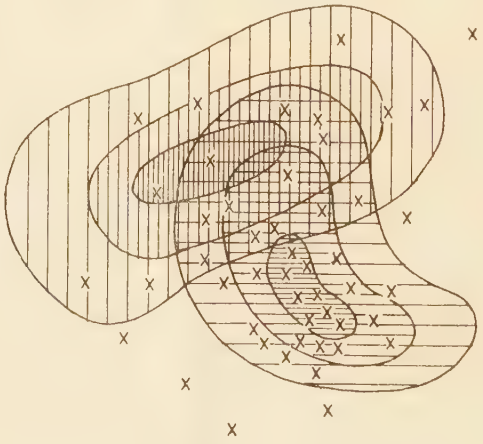

Fig.7. *The error of location*

Hypothetical distributions of herring (vertical lines) and diatoms (horizontal lines), with sampling stations randomly distributed across both patches.

The second form of error, the error of location, may be illustrated by a diagram (Fig. 7). This shows a patch of herring and a patch of diatoms in an apparent position of exclusion. Whether it actually is or not, depends on what has happened before and what is going to happen after the patches were observed; this single observation merely means that the two patches were in these positions. It can, however, be said that an exact point to point coincidence in abundance of fish and plant patches is very improbable. Now, any other distribution, than point to point coincidence, will show an 'exclusion' in varying degree, because the regions of high abundance of fish and plants are bound to be apart. Then, one finds high herring catches in regions of low plant numbers and vice versa. This error of location arises particularly if it is spread across different patches and different arrangements in time. There is an absurd extension to this argument: high catches of herring may be related to low plant densities and nil catches to high plant densities, which may be far from the herring patch. There is room in the region of the East Anglian fishery for a diatom sample to be remote from a herring patch, merely because fish are absent, the observed drifter not having found them, and not because they have been excluded. It is suggested that the error of location is responsible for the results given in Henderson *et al.* (1936).

If the herring come to Smith's Knoll every year and if diatom concentrations are randomly arranged around a large area from Smith's Knoll, one might expect that the exclusive effect of plants would shift the drifter fleets. Yet the herring drifters come every year to their traditional positions.

The error of location can be possibly applied to Professor Hardy's original table, for which Fig. 6 shows the distribution of landings. High herring catches, with one exception, are centred on Smith's Knoll, the traditional area; low herring catches are found later to the south, in a region that happens in this case to be filled up with *Phaeocystis*. If the geographical positions of high and low catches had been reversed, I should not have been able to assert that the highest catches were found in the traditional places. If one separates the catches in two, those near Smith's Knoll and those away from it, one finds that there is one low catch near the Knoll and one high catch away from it. The other pairs of observations are all high, near the Knoll in clear water, or low, away from the Knoll in weedy water. It is suggested that proximity to Smith's Knoll is as good a reason for high catches as lack of *Phaeocystis*.

The results given in this paper, show that exclusion, as measured by the correlation coefficient between catches of herring and densities of *Rhizosolenia styliformis*, does not take place. There is no real difference between the method used here and that used by Hardy (1926) and Henderson *et al.* (1936) except that the whole correlation was carried out within 18 hours on the same patches of fish and plants. No serial error was possible and the error of location was minimal because the plant patch and fish patch coincided as nearly as is possible. The fact that this improbable and lucky distribution could take place when the densities of plants reached 100,000/m.^{3} means that it is very improbable that exclusion could take place up to this density.

2. Deflection of Migration

The first evidence on the deflection of migration is given by Savage (1930). A patch of *Phaeocystis* was found across the assumed path of migration of the herring; this was discovered after there had been a temporary decline in landings at the ports. At the same time, the area of the fishery was said to be centred 30 miles ENE of Smith's Knoll, due south of the centre of the *Phaeocystis* patch. Yet, the Official Report for this year states: 'even as far as 60–70 miles to the north-east, where, as events subsequently proved, the chief centre of fishing remained throughout the season". This point is in the centre of the *Phaeocystis* patch. (Quoted in Savage and Hardy (1935), p. 26.)

The region 30 miles ENE of the Knoll is one normally fished by the Dutch and German luggers. The average catch for 1st–7th November was not below the average for the first week in November from 1922–32; in fact, it was higher than average. Thus the decline in landings can only have been of two or three days' duration. If the change in position of the English and Scottish drifters was due to a deflection of migration one would expect that the German luggers would be found to the eastward of the patch of *Phaeocytis*. In fact no such landings

were made as is apparent from Fig. 8, and the eastern limit of the fishing area is seen to
that of a normal season. The migration route as shown by these landings was unchanged.

The evidence that the English and Scottish fishery was moved 30 miles ENE or
becomes significant if it is known that patches of *Phaeocystis* exclude the herring. As t
evidence for this exclusion is open to doubt, we can merely say that the fishery moved, b
not that the movement was related to the concomitant patch of *Phaeocystis*.

After the publication of Savage's (1930) paper describing the events given abov
Savage and Hardy (1935) published a paper in which the idea is developed that the herri

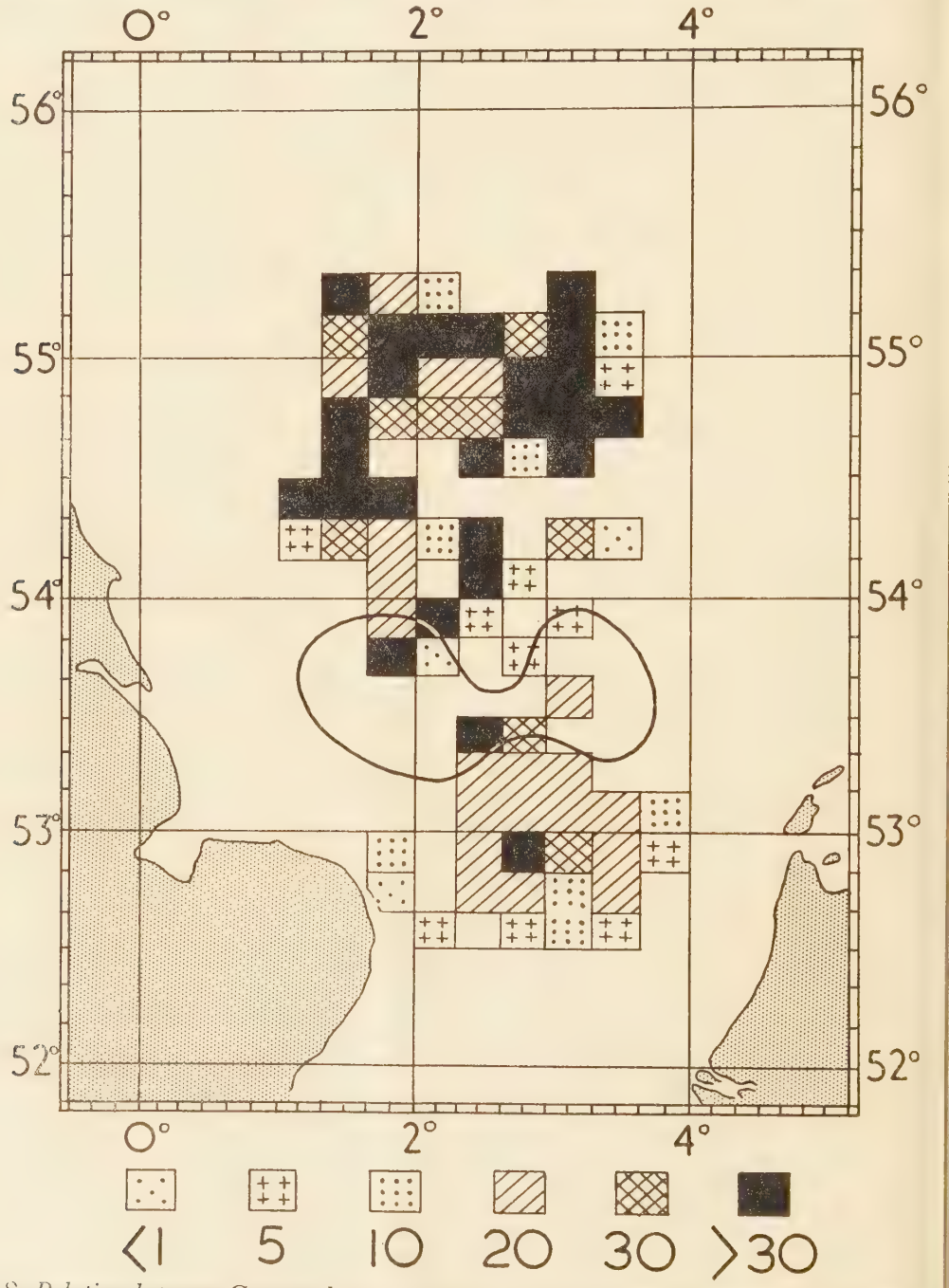

Fig. 8. *Relation between German lugger landings in October and November*, 1927 *and t*
Phaeocystis *patch* (*from Savage*, 1930) *in line.*

migrations are discouraged, deflected and delayed by the phytoplankton barrier. It was generally assumed that herring approach the East Anglian fishery from all possible northern directions; thus a patch of plants in any position to the north was said to have a discouraging effect on migration.

In 1950 it was shown that the herring did migrate in very much the direction that was shown in the German lugger landings for many years, i.e. from the north and not the north-west or the north-east. Much of the detailed evidence given in Savage and Hardy can thus be discounted.

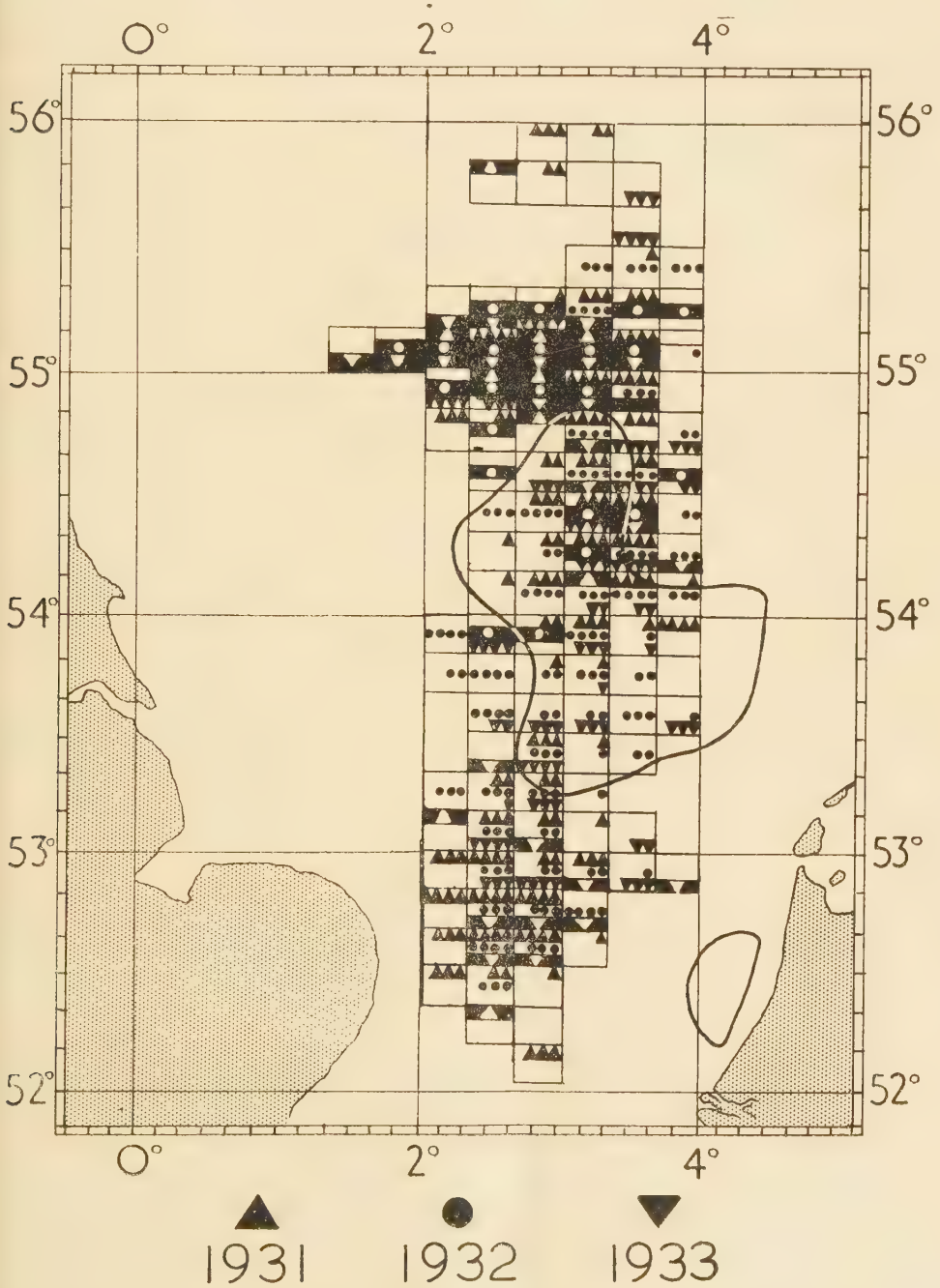

Fig. 9. *Relation between the phytoplankton patch at* 500,000 *cells/m.*^{3} (*from Savage and Wimpenny,* 1936) *and the German lugger landings,* 1931-3.

The main piece of evidence in Savage and Hardy (1935) is as follows. Deviations from the mean of 10 years' catches are presented as weekly values in each season from 1922–32 in a diagram (Fig. 28, Savage and Hardy 1935). Negative deviations are often said to be related to the presence of a phytoplankton patch in the southern North Sea and positive deviations are said to be related to the lack of such a patch. It is noticed that these effects are sometimes complicated by the effects of abundance of year classes, weather, lunar effects and economic effects. In 1921, the 4 and 5 year classes were poor; in 1922 these had become 5 and 6 year classes and in 1923 they were 6 and 7's. The figure shows that in these three years, the negative deviations occur progressively later, as these poor year classes would appear in the fishery. In subsequent years the effect of the phytoplankton patches is not at all marked, except in 1926 when there were very poor 6–8 year classes and in 1932, when the market was poor.

The paper by Savage and Hardy assumed that variations in the fishery were likely to be caused by the presence of plant patches, delaying the appearance of the herring. Savage and Wimpenny (1936) showed that such a delay did occur. Doctor Hodgson had been led to expect a very early start to the fishery (forecast published on 12th August, 1933); this was related to the full moon on 3rd October. The fishery did not develop properly until 21st October. Thus there appeared to have been a delay of about three weeks associated with an exceedingly dense patch of the diatoms *Rhizosolenia styliformis* and *Biddulphia sinensis* – about 7,400 square miles in extent at a density of at least 1,300,000 cells/m.^{3}.

Doctor Hodgson's forecast of 1933 had neglected a factor that was discovered later. It was found that when the full moon occurs before 12th October, the fishery does not build up quickly. This fact first appeared in Savage and Hodgson (1934). There is only one peak to the fishery, occurring at the date of the November full moon. Thus, the fact that landings did not develop until 21st October is quite normal – there was in fact no delay at all. This is all the more remarkable in face of the extent and density of the phytoplankton 'barrier'.

If deflection of migration does occur, it should have taken place in 1933. Fig. 9 shows the outline of the patch of both diatoms at a density of 500,000 cells/m.^{3} superimposed upon the German lugger landings for 1931, 1932 and 1933. It is immediately obvious that there is no real difference between the distributions of lugger landings shown for the three years and that there was no deflection of migration as shown by the lugger landings for the three years concerned. The same track is given in 1934, 1935 and 1936.

The results given in this paper show that in detail there was no deflection of migration as shown by the zigzag method in and out of the plant patch and that there was no deflection of migration shown in the surveys during 1950. Thus the case for deflection of migration and delay of migration is not proven, which is not surprising if doubt is accepted on the principle of exclusion.

3. Conclusion

It is concluded that migration of the herring from the South-West patch of the Dogger to the Norfolk Banks is not affected by the plant concentrations that have been shown to occur in this area. Official warnings to the herring fleet have therefore ceased, but a watch is maintained for very strong outbursts that might have effects beyond the range dealt with in this paper.

It is thought that the 'exclusion' noticed by Pearcey (1885) and Bullen (1908) in summer feeding fisheries, is really a consequence of herring aggregating where *Calanus* have grazed as Harvey (1934) has suggested. It is doubtful if there is any corresponding phenomenon in the East Anglian fishery, where the herrings are not feeding.

We must note that these results are not comparable with the poisonous effect of phytoplankton that is so often recorded in marine, brackish water and fresh water. For example, the densities of dinoflagellates recorded in such epidemics are: 14,–60,000,000/litre of *Gymnodinium brevis* (Gunter, Williams, Davis and Walton Smith (1948)) 1,200,000,000/litre of *Prymnesium parvum* (Otterstrøm and Steeman Nielsen). Again Sommer, Whedon, Kofoid and Stohler (1937) have shown that 3,000 *Gonyaulax catenella* will kill a mouse, but diatoms at a density of 10,000,000/litre have no toxic effect.

APPENDIX

Table 1: Platessa, *Cruise XXIX*, 1948

Date	Station	Position	*R. styliformis*/m.³	Mean density	No. of soundings
7 Oct. 48	1	53°29′N., 2°30′E.	6300		
				4462	8
7 Oct. 48	2	53°31′N., 2°46′E.	2625		
				2400	17
8 Oct. 48	3	53 36½′N., 2 35′E.	2175		
				5885	22
8 Oct. 48	4	53°46′N., 2°42′E.	9596		
				10191	–
8 Oct. 48	5	53°52′N., 2°38′E.	10787		
				11956	–
8 Oct. 48	6	53°51′N., 2°11′E.	13125		
				7987	16
8 Oct. 48	7	53°42′N., 2°00′E.	2850		
		Mean density over the area 7147/m.³			

Note: The echo sounder used on *M.V. Platessa* was not comparable with those used on *R.V. Sir Lancelot* and *R.V. Clupea*, so the following indices were used: Small=1, Medium=2, Large=3, Very large=4.

Table 2: Clupea, *Cruise II*, 1948

Date	Station	Position	No. of *R. styliformis*/m.³	Mean density	No. of soundings	Time in minutes	No. of soundings per unit distance between stations
6 Oct. 48	1	53°48′N., 00°58′E.	–				
6 Oct. 48	2	53°48′N., 01°07′E.	–				
6 Oct. 48	3	53°48′N., 01°16′E.	–				
6 Oct. 48	4	53°48′N., 01°24′E.	–				
6 Oct. 48	5	53°48′N., 01°33′E.	–				
6 Oct. 48	6						
6 Oct. 48	7	53°53½′N., 01°40′E.	–				
6 Oct. 48	8	53°58′N., 01°40′E.	5185				
6 Oct. 48	9	54°04½′N., 01°40′E.	14559				
6 Oct. 48	10	54°10′N., 01°40′E.	22500				
6 Oct. 48	11	54°04′N., 01°31′E.	10781				
				7027	8	50	0·16
6 Oct. 48	12	53°56½′N., 01°44′E.	3273				
				18112	–	–	0·0
7 Oct. 48	13	53°51′N., 01°30′E.	32952				
				33351	–	–	0·0
7 Oct. 48	14	53°54′N., 01°36′E.	33750				
				38693	5	32	0·19
7 Oct. 48	15	53°51½′N., 01°20′E.	43636				
				41590	11	88	0·125
7 Oct. 48	16	53°45′N., 00°55′E.	39545				
7 Oct. 48	17	53°52′N., 00°56′E.	–				

Table 3: Sir Lancelot, *Cruise XX*, 1948

Date	Station	Position	No. of *R. styliformis*/*m.*³	Mean density	No. of soundings	Time in minutes	No. of soundings per unit distance between stations
4 Oct. 48	1	53°19′N., 01°18′E.	–	146	–	–	–
4 Oct. 48	2	53°19′N., 01°52′E.	293	521	–	–	–
4 Oct. 48	3	53°19′N., 02°27′E.	750	4164	–	–	–
4 Oct. 48	4	53°19′N., 03°00′E.	7579	16849	–	–	–
5 Oct. 48	5	53°35′N., 03°00′E.	26120	18435	–	–	–
5 Oct. 48	6	53°35′N., 02°31′E.	10750	6687	–	–	–
5 Oct. 48	7	53°35′N., 02°01′E.	2625	1312	–	–	–
5 Oct. 48	8	53°35′N., 01°32′E.	–	–	9	37	0·24
5 Oct. 48	9	53°35′N., 00°59′E.	–	44408	7	44	0·16
5 Oct. 48	10	53°50′N., 00°59′E.	88816	60738	16	44	0·36
5 Oct. 48	11	53°50′N., 01°30′E.	32661	19859	18	38	0·47
5 Oct. 48	12	53°50′N., 02°00′E.	7057	10517	28	43	0·65
5 Oct. 48	13	53°50′N., 02°30′E.	13977	8783	4	33	0·12
5 Oct. 48	14	53°50′N., 03°00′E.	3589	3955	7	34	0·21
6 Oct. 48	15	54°05′N., 03°00′E.	4322	2390	–	–	–
6 Oct. 48	16	54°05′N., 02°30′E.	459	974	–	–	–
6 Oct. 48	17	54°05′N., 02°00′E.	1489	7392	45	106	0·42
6 Oct. 48	18	54°05′N., 01°30′E.	13295	8181	–	–	–
6 Oct. 48	19	54°05′N., 01°00′E.	3068	2828	–	–	–
6 Oct. 48	20	53°42′N., 01°00′E.	2588	–	–	–	–
6 Oct. 48	21	53°47′N., 00°54′E.	–	–	–	–	–
6 Oct. 48	22	53°47′N., 00°45′E.	–	–	–	–	–
6 Oct. 48	23	53°52′N., 00°45′E.	–	–	9	32	0·28
6 Oct. 48	24	54°02′N., 00°45′E.	–	–	–	–	–
6 Oct. 48	25	54°07′N., 00°45′E.	–	–	5	9	0·56
6 Oct. 48	26	54°07′N., 00°36′E.	–	–	–	–	–
6 Oct. 48	27	54°05′N., 00°31′E.	100	102	–	–	–
6 Oct. 48	28	54°04½′N., 00°39′E.	105	8252	–	–	–
6 Oct. 48	29	54°03½′N., 00°47′E.	16400	8387	–	–	–
6 Oct. 48	30	54°02½′N., 00°38′E.	375	266	–	–	–
6 Oct. 48	31	54°01½′N., 00°30′E.	157	106	–	–	–
6 Oct. 48	32	54°01′N., 00°38′E.	56	335	–	–	–
6 Oct. 48	33	53°59½′N., 00°46′E.	614	391	–	–	–
6 Oct. 48	34	53°58½′N., 00°38′E.	169	84	–	–	–
7 Oct. 48	35	53°58′N., 00°30′E.	–	729	–	–	–

Table 3: Sir Lancelot, *Cruise XX*, 1948 *continued*

Date	Station	Position	No. of *R. styliformis*/m^3	Mean density	No. of soundings	Time in minutes	No. of soundings per unit distance between stations
Oct. 48	36	53°57′N., 00°38′E.	1459				
				8939	2	11	0·18
Oct. 48	37	53°56′N., 00°45′E.	16419				
				12034	8	10·7	0·75
Oct. 48	38	53°55′N., 00°37′E.	7650				
				3853	5	8	0·62
Oct. 48	39	53°54′N., 00°29′E.	56				
				2181	–	–	–
Oct. 48	40	53°53′N., 00°37′E.	4307				
				33244	11	10	1·10
Oct. 48	41	53°52′N., 00°45′E.	62182				
				31670	147	34·4	4·27
Oct. 48	42	53°49½′N., 00°42′E.	1159				
				652	28	43	0·65
Oct. 48	43	53°45½′N., 00°38′E.	145				
				1947	3	12	0·25
Oct. 48	44	53°48½′N., 00°45′E.	3750				
				1875	54	78	0·69
Oct. 48	45	53°51½′N., 00°52′E.	–				
				12375	59	69	0·86
Oct. 48	46	53°55′N., 00°58′E.	24750				
				24830	–	–	–
Oct. 48	47	53°52′N., 01°17′E.	24911				
				19486	52	120	0·43
Oct. 48	48	53°48′N., 01°33′E.	14062				

Table 4: Catches per drifter in crans and densities per m.³ of R. styliformis

Serial Number	October, 1948	*R. styliformis*/m.³	Crans
1	8	3,115	3
2	8	433	1¾
3	7	104,167	9
4	8	6,500	43½
5	7	74,423	–
6	7	117,188	2
7	7	77,850	15
8	8	26,631	3¼
9	7	75,288	–
10	7	35,812	17
11	7	10,212	18¼
12	7	2,250	–
13	7	818	1
14	7	716	33
15	7	27,000	3
16	7	51,750	2
17	7	10,739	–
18	7	27,375	20
19	7	57,188	7
20	7	20,025	3
21	7	76,875	–
22	7	81,562	1¾
23	7	–	–
24	7	2,250	22
25	7	2,856	2
26	7	173	–
27	7	260	6¾
28	7	–	1¼
29	7	2,250	–
30	7	1,266	2
31	7	1,009	–
32	7	33,562	35
33	7	48,989	1¼
34	8	1,125	8
35	7	24,750	20
36	8	5,452	3¾
37	8	2,812	1
38	8	375	7
39	8	3,044	5
40	8	2,170	13¾
41	8	2,812	15
42	8	600	2¼
43	8	3,234	1
44	8	469	4
45	7	1,739	–
46	7	1,330	1¼
47	8	273	2¾
48	7	2,352	¼
49	8	2,045	–
50	8	1,038	1
51	8	173	1½
52	7	536	49
53	7	55,125	–
54	8	12,283	6
55	7	47,596	¾
56	7	56,250	10
57	7	57,375	1
58	7	135,938	25
59	6	3,635	1
60	8	5,833	½
61	8	6,083	3
62	6	21,000	–

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